MICROWAVE MEDICAL IMAGING AND DIAGNOSTICS

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Abstract: Future trends in medical applications of microwave technique and technology can be seen in development of new diagnostic and imaging methods based on high frequency em field. A significant importance for the future can be identified for the following methods: microwave tomography, microwave radiometry, measurement of complex permittivity, imaging in the terahertz waves band and microwave diagnostic radars.

Introduction

Interactions of EM field with biological systems are utilised in the area of therapy (oncology, physiotherapy, urology atp.) from late seventieth of last century. Wideutilization of microwave thermotherapy can be observed in the countries of EU, USA and Japan. Our activities in microwave thermotherapy in former Czechoslovakia started in the year 1981. Since 1990 we are member of ESHO (European Society for Hyprthermia Oncology), which co-operates with NAHS (North American Hyperthermia Society) and ASHO (Asian Society of Hyperthermia Oncology).

Recent trends in microwave medical applications are to study the possibilities to develop new diagnostics based on EM field resp. on microwace technique. A significant importance for the future can be identified for the next methods:

- Magnetic resonance,
- Microwave tomography,
- Microwave radiometry,
- Measurement of complex permittivity,
- Imaging with terahertz waves,
- Microwave diagnostic radar.

We will not talk here about magnetic resonance, as it is just well known and broadly used application of EM field in medical diagnostics. We will focus here on other above mentioned methods (excluding microwave diagnostics radars).

Microwave applicators for medical imaging and diagnostics

Since 1981 we develop waveguide applicators working in frequency band from 27 MHz up to 2450 MHz. These applicators were used for the treatment of more then 1000 patients with superficial or sub-cutaneous tumors (up to the depth cca 4 – 6 cm). Now, following new trends in this field, we continue our research in the important directions of deep local and regional applicators. We have found, that quite similar applicators are optimal to be used for medical imaging and diagnostics.

Examples of mentioned applicators are given in the Fig. 1. Both applicators have aperture 18 x 12 cm and are operating at 434 MHz. Waveguide applicators in Fig. 1 (on the left side) are filled by dielectric material in order to decrease their cut off frequency Evanescent mode applicator (Fig. 1 – on the right side) is excited under its cut-off frequency..

Figure 1: Dielectric filled waveguide applicator and Evanescent mode applicator.

On the next figure there is a sketch of applicator working at 70 MHz and its SAR distribution – including influence of water bolus between applicator and phantom of biological tissue.

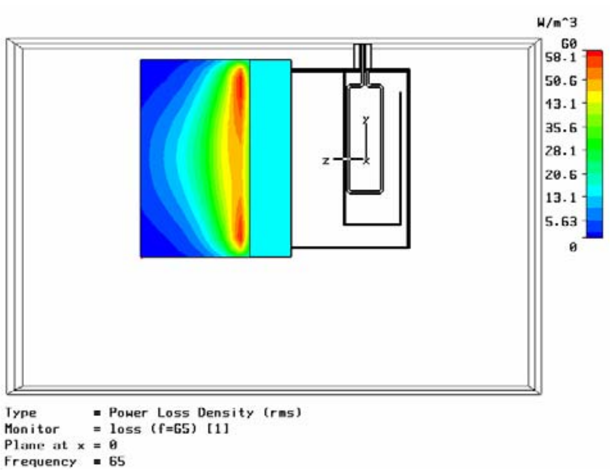

Figure 2: Evanescent mode applicator and its calculated SAR pattern

Interesting possibility how to achieve relatively sharp beam from external applicator is to use a focusing principle. The aperture of a standard rectangular waveguide applicator is divided into 3 or 5 sectors with shifted excitation (i.e. different amplitude and phase). The basic schematics of this lens type applicator is shown in the following figure.

Microwave tomography

Microwave tomography [1] is in general application of basic CT principals but by utilization of microwave band. Scattering of EM waves in non-homogeneous human body is however much more complicated than simple attenuation of ionising radiation. Therefore development of microwave tomography is conditioned by new theoretical approach, optimization of evaluation algorythms and more efficient computer technique.

An experimental setup is schematically shown on next figer. Studied object will be placed in water phantom. It will be irradiated by transmitting antenna while scattered EM field will be monitored by receiving antenna and evaluated by a network analyser. Receieving antenna will be scanning around studied object and/or it will be possible to move/rotate the studied object. Measured data will be then reconstructed on the basis of Fourier transform.

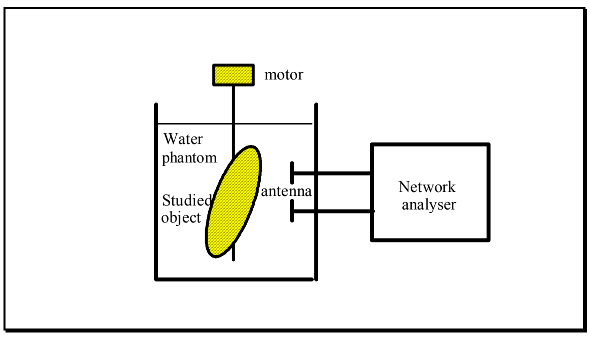

Figure 3: Schematics of experimental setup of microwave tomograph for biomedical imaging

Microwave tomography represents applications of CT known principals to microwave frequency band, where in general situation is more complicated because of much more complicated propagation of EM waves. Therefore mathematical model should be created and optimized evaluation algorithms are needed and last but not least – powerful computers are necessary for the calculations.

Microwave radiometry

Microwave radiometry is based on measurement of a very weak EM signal, which radiate any object (e.g. people), whose temperature is superior to absolute zero [1]. It is based on utilization of so-called Planck radiation law. Interest in microwave radiometry is given by possibility of its utilization at diagnostics of cancer and also of inflammatory disorder (e.g. appendicitis, arthritis, atp.) because tumors and inflammatory processes causes temperature rise. Microwave radiometer as a tool for biomedical imaging applications has the possibility to „monitore“ a thermal noise produced by objects with the temperature over absolute zero. Next figure gives a basic idea about experimental setup. Advantage of microwave radiometer is ability to „see“ the temperature increase under the surface of human body. Therefore wee need to scan studied area of the tissue with a sensor and to evaluate the results of temperature measurements.

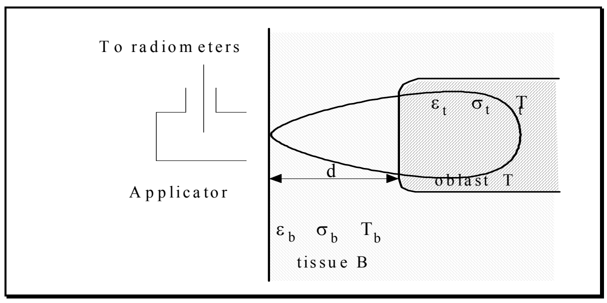

Figure 4: Principals of imaging by a microwave radiometer

Let us suppose, that applicator (antenna of the radiometer) is situated on the layer B of the monitored biological tissue. Thicknes of this layer is d and it temperature T_b. Its dielectric parameters will be ε_b a σ_b.

Further we have in this figure region of biological tissue T (in the depth d) where temperature is $T_t = T(z)$ and dielectric parameters are ε_t a σ_t. Then we can apply following equation to determine the temperature measured by discussed microwave radiometer

$$T_r = 2\int_0^d \beta(z).T(z).e^{-2\int_0^z \beta(z').dz} dz + T_d.e^{-2\int_0^d \beta(z').dz}$$

where $\beta(z)$ is attenuation in the studied area. Often we can simplify this case in following way

$$\beta(z) = \beta$$

Then initial equation can be rewritten as follows

$$T_r = 2\beta \int_0^d T(z).\mathrm{e}^{-2\beta z} dz + T_d.\mathrm{e}^{-2\beta d}$$

If also temperature *T(z)* will be constant and equal to T_b, then we can use modified expression to determine the temperature measured by discussed microwave radiometer

$$T_r = (1 - \frac{1}{L_b})T_b + \frac{1}{L_b}T_t$$

where L_b is attenuation of the layer B for electromagnetic wave at given frequency.

In the case of low level of L_b then radiometer will see the tempearture of region T, i.e. T_t. If L_b will increase, then reading of radiometer will approach to value of T_b.

In the next figure we can see relation between discussed quantities for the case, when T_b = 310 K and T_t = 312 K and sensitivity of a radiometer is 0,5 K so we can detect increase in temperature for levels of 310,5 K. Temperature measured by radiometer is in this figure a function of L_b.

According to this figure attenuation in region B can be only 6 dB at maximum, othervise radiometer “will not see” increased temperature in region T.

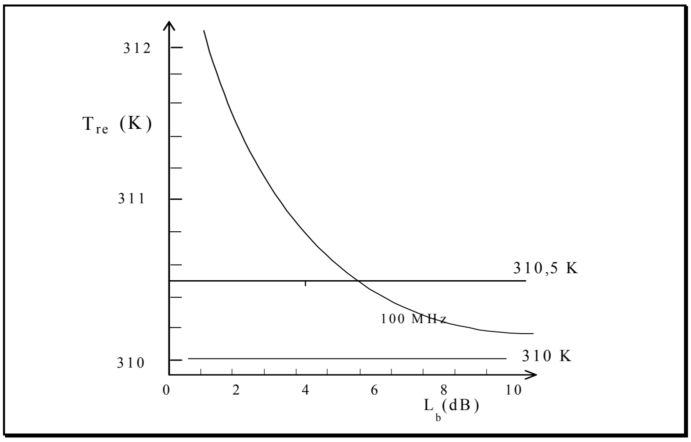

Figure 5: Temperature measured by radiometer with respect to tissue attenuation L_b.

At following figure there are the graphs of the temperature which would be measured by a radiometer at different frequencies.

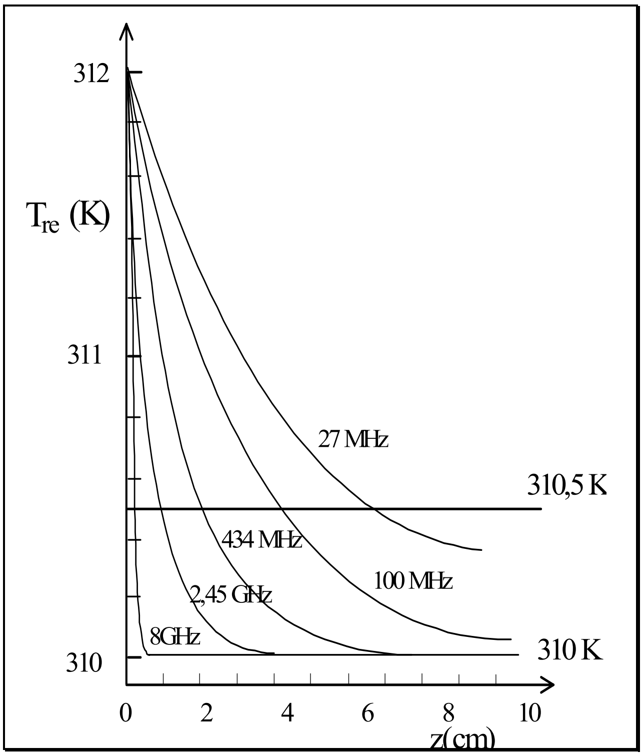

Figure 6: Temperature measured by radiometer with respect to tissue attenuation at different frequencies.

Mesurements of complex permittivity

Measurements of complex permittivity „in vivo“ could be a suitable for biomedical imaging applications [1]. Usually an open end of coaxial line is used as a very suitable sensor for this measurement. Scanning the studied object by a such probe can bring us a map of the permittivity – we can then evaluate symmetry resp. unsymmetry of the measurement results and from this information we can make hypothesis about possible medical problems.

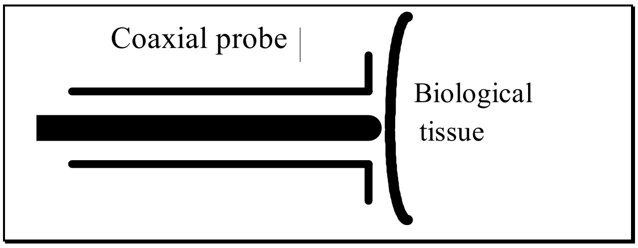

Figure 7: Coaxial probe for measurement of .

Characteristic impedance is Z_o. C_o and C_f are fringing capacities in the equivalent circuits, which can be determined by aid of calibration methods. Reflection coeficient can be determined as

$$\varrho = |\varrho| \mathrm{e}^{j\varphi}$$

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Then for complex permitivity (its real and imaginery part) can be derived following equation

$$\varepsilon' = \frac{-2|\varrho|\sin\varphi}{\omega C_o Z_o(1+2|\varrho|\cos+|\varrho|^2)} - \frac{C_f}{C_o}$$

$$\varepsilon'' = \frac{1-|\varrho|^2}{\omega C_o Z_o(1+2|\varrho|\cos+|\varrho|^2)}$$

Imaging with terahertz waves

Frequency band of so called Terahertz waves (0.1 – 10 THz) is being studied during last years [1]. We can expect here a lot of new discoveries in material science and in biomedicine as well, especially for imaging purposes.

Theoretical models and a feasibility study can be based on similar principles as Microwave Radiometer and Infrared Camera Imaging.

Terahertz waves are "situated inbetween" microwave frequency band and infrared band. Therefore we can expect following properties:

1) Terahertz waves compared to microwaves will ofer better space resolution, but somewhat worse capability to recover image from deep positions.

2) On the contrary, comaprison of terahertz waves to infrared will result in better capabilty to recover image from deeper position but its space resolution will be worse.

Conclusions

As novel results of our work we could mention that waveguide applicators and prospective methods for microwave medical diagnostics have been described and discussed.

Acknowledgements

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References

[1] VRBA, J., (2003): Medical Applications of Microwaves' (In Czech). 1. ed. Prague : Issued by CTU, 2003. 168 p. ISBN 80-01-02705-8.

[2] SEMENOV, S.Y. et al. , (2002): 'Three-Dimensional Microwave Tomography, Initial Experimental Imaging of Animals'. IEEE Transactions on BME, Vol. 49, No. 1, Jan. 2002, pp. 55 – 63

[3] GABRIEL, S., LAU, R.W., GABRIEL, C. , (1996): „The dielectric properties of biological tissue – II. measurements in the frequency range 10 Hz to 20 GHz'. Phys. Med. Biol. vol. 41, pp. 2251-2269, 1996

[4] FEAR, E.C., STUCHLY, M.A. , (2000): „Microwave detection of breast cancer'. IEEE Trans. Microwave Theory tech. vol. 48, pp. 1854-1863, 2000

[5] VRBA, J. et al. , (2003): 'Technical Aspects of Microwave Thermotherapy'. RF Interaction with Humans: Mechanisms, Exposures and Medical Applications. IPEM Meeting, Institute of Physics, London, February 2003

[6] VRBA, J., FRANCONI, C. MONTECCHIA, F., VANUCCI, I. , (1993): 'Evanescent Mode Applicators for Subcutaneous Hyperthermia'. IEEE Trans. on Biomedical Engineering, Vol.40, No 5, May 1993, pp. 397 - 407

[7] FRANCONI, C., VRBA, J., MONTECCHIA, F. , (1993): '27 MHz Hybrid Evanescent-Mode Applicators with Flexible Heating Field for Deep Hyperthermia'. International Journal of Hyperthermia, 1993, Vol. 9., No. 5., pp. 655 - 673